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FINAL REPORT  
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A HIGH-RESOLUTION FOURIER TRANSFORM SPECTROMETER  
FOR PLANETARY SPECTROSCOPY

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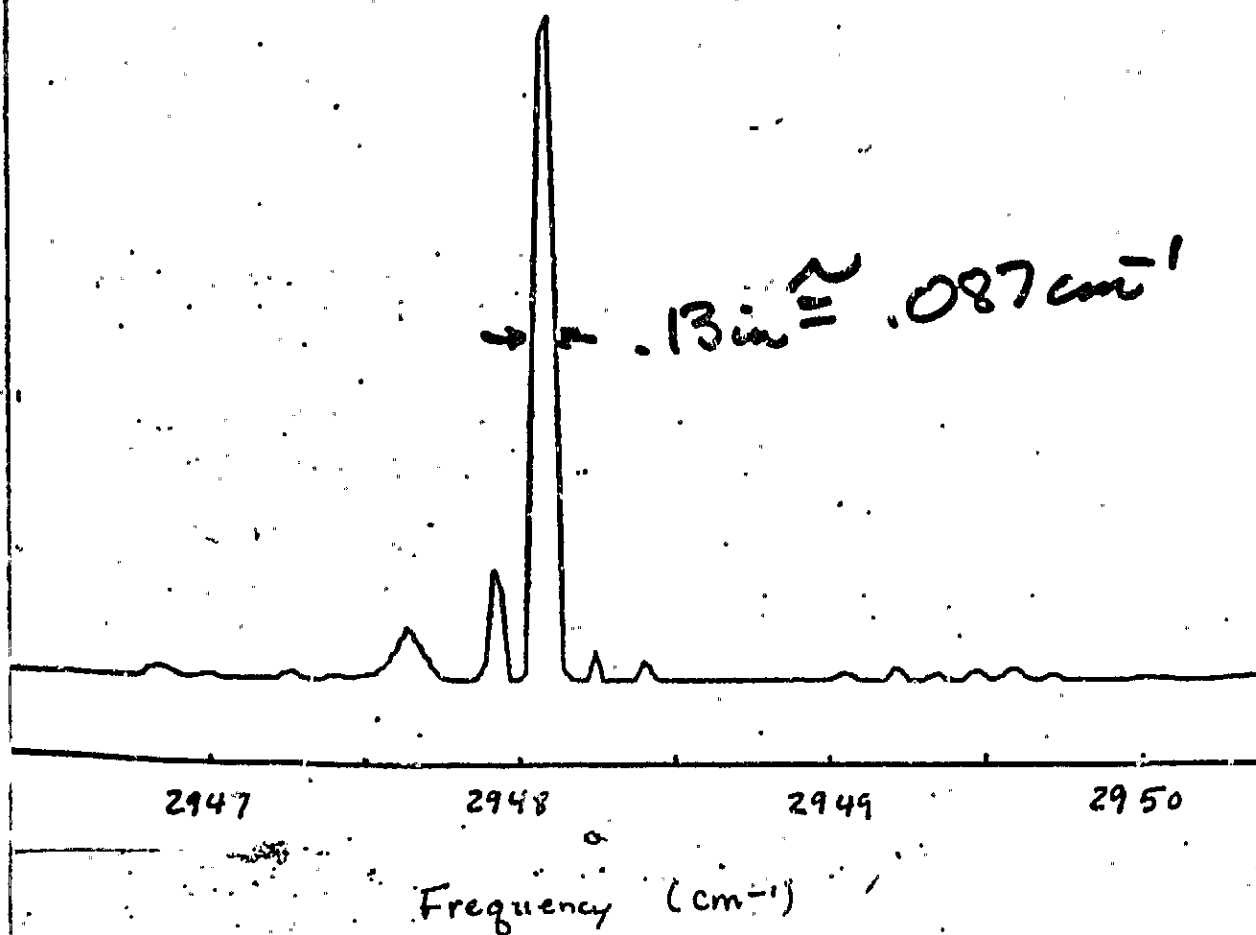
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Figure 3.

Line of He-Ne laser at  $3.39 \mu$ .

Unapodized spectrum



The duty cycle is sufficiently efficient at resolution  $8 \text{ cm}^{-1}$  to justify use of that resolution for faint astronomical sources where the total observing time must be maximized in order to establish an adequate detection.

The interferometer uses a He-Ne laser to provide a monochromatic interferogram which is used in a tight servo loop to control the velocity of the scan. A white light interferogram, generated in the reference interferometer, is used as a trigger pulse for the initiation of the scan and data collection cycle. The highest sampling frequency is 10 kHz, though we have provisions for extending this to 25 kHz. Data from each scan are co-added in phase in a Nova disk (capacity 128 K) file. A large number of scans can be co-added and then transformed to obtain the spectrum. The transformation is facilitated by a hardware multiply-divide unit made by Digilab. The complete transformation of a 32 K-point interferogram (single precision) requires less than five minutes in the Nova. The transformed spectra can be stored on the Nova disk or on magnetic tape. The magnetic tape unit makes it possible to store an indefinite number of spectra and raw interferograms.

The Nova system permits manipulation of the interferograms and spectra at the desire of the operator. Interferograms can be averaged or ratioed, as can spectra. Once the basic interferogram is stored on tape or on the disk, it can be readily moved into the operation file and apodized, or plotted at any desired scale. The speed and ease of working with the data system makes it possible to keep a close watch on the progress of data acquisition. A typical operational technique is to obtain interferograms in blocks of 256 scans, store the blocks on tape, which procedure minimizes loss of observing time. The interferograms can later be transformed and spectrum averaged, or can be averaged before the transformation is accomplished.

## Introduction

This is the final report on the project to acquire and employ a high-resolution Fourier Transform Spectrometer (FTS) for planetary and other astronomical spectroscopy in conjunction with the 88-inch telescope at Mauna Kea Observatory.

After considerable deliberation, we decided on the purchase of a commercially available FTS complete with self-contained data system, but with custom designed and built sky compensation system. The basic FTS instrument and data system were supplied by Digilab, Inc. and the sky compensation system was designed and built by Block Engineering, Inc., both of Cambridge, Mass. The Digilab FTS system was designed for a broad range of uses, including double-beam laboratory spectroscopy, infrared gas chromatography, and nuclear magnetic resonance spectroscopy. The data system is well-suited to astronomical applications because of its great speed in acquiring and transforming data, and because of the enormous storage capability of the magnetic tape unit supplied with our system.

In this report, we will outline the basic instrument that we have obtained from Digilab/Block and append some of the initial results from the first attempted use on the Mauna Kea 88-inch telescope.

## The Instrument

The FTS system consists of two basic units, the optical Michelson interferometer, and the data system. Both are built around and are dependent upon a Nova 1200 mini-computer. The interferometer is a rapid-scan type built upon principles established by L. Mertz about ten years ago. Its maximum scan length is 5 cm, giving a maximum beam retardation of 10 cm, which corresponds to maximum spectral resolution  $0.1 \text{ cm}^{-1}$ , or one part in  $10^5$  at wavelength 1  $\mu\text{m}$ . The scan length, and thus the resolution, are variable from the equivalent of  $16 \text{ cm}^{-1}$  to  $0.1 \text{ cm}^{-1}$ .

noise sources in the preamplifiers, the InAs detector, and possibly in the co-adding. Our intent is to attack these sources of noise and to ultimately achieve s/n sufficiently high to permit us to obtain spectra of stars having K magnitude +2 at resolution  $2 \text{ cm}^{-1}$  in four hours observing time.

Figure 2 shows a lunar spectrum at resolution  $1 \text{ cm}^{-1}$ , while Figure 3 shows the unapodized spectrum of the  $3.3\text{-}\mu\text{m}$  He-Ne laser line at the maximum achievable resolution of the FTS system ( $0.08 \text{ cm}^{-1}$ ).

#### Future Programs

As enumerated in the proposals for funding of this project, our main interests are in high-resolution planetary spectra of Jupiter, Saturn, Mars, and Venus. When the sensitivity of the instrument is maximized, it will prove an important tool for obtaining stellar spectra as well, thus opening up a wide variety of topics for study in the field of stellar atmospheres. We also expect to use the system for low-resolution spectroscopy of small bodies in the solar system, such as bright asteroids and satellites.

One justification for the installation of an infrared spectrometer at Mauna Kea has been to take advantage of the dryness of the site with the consequent spectral transparency even in fairly strong telluric absorption bands. The realization of this goal is demonstrated in a preliminary way by the spectrum of Alpha Orionis in Figure 1. The telluric  $\text{H}_2\text{O}$  band at  $1.9 \mu\text{m}$ , commonly saturated at lower-altitude observing sites, is absorbed only about 60 percent as seen from Mauna Kea. High resolution spectra from Mauna Kea on its ordinarily dry nights should permit the detection of strong stellar features amid the water

vapor lines in this band.

Summary

A high-resolution Fourier transform spectrometer and data system has been acquired in accordance with the original plan. Initial results on astronomical spectra are promising but not at the ultimate desired level of sensitivity. The improvement of the system, which will largely be undertaken by Institute scientists, is expected to result in high-quality astronomical spectra for planetary and stellar research.

Figure 1.

$\alpha$  Orionis, resolution  $8\text{ cm}^{-1}$

Detector  
cutoff

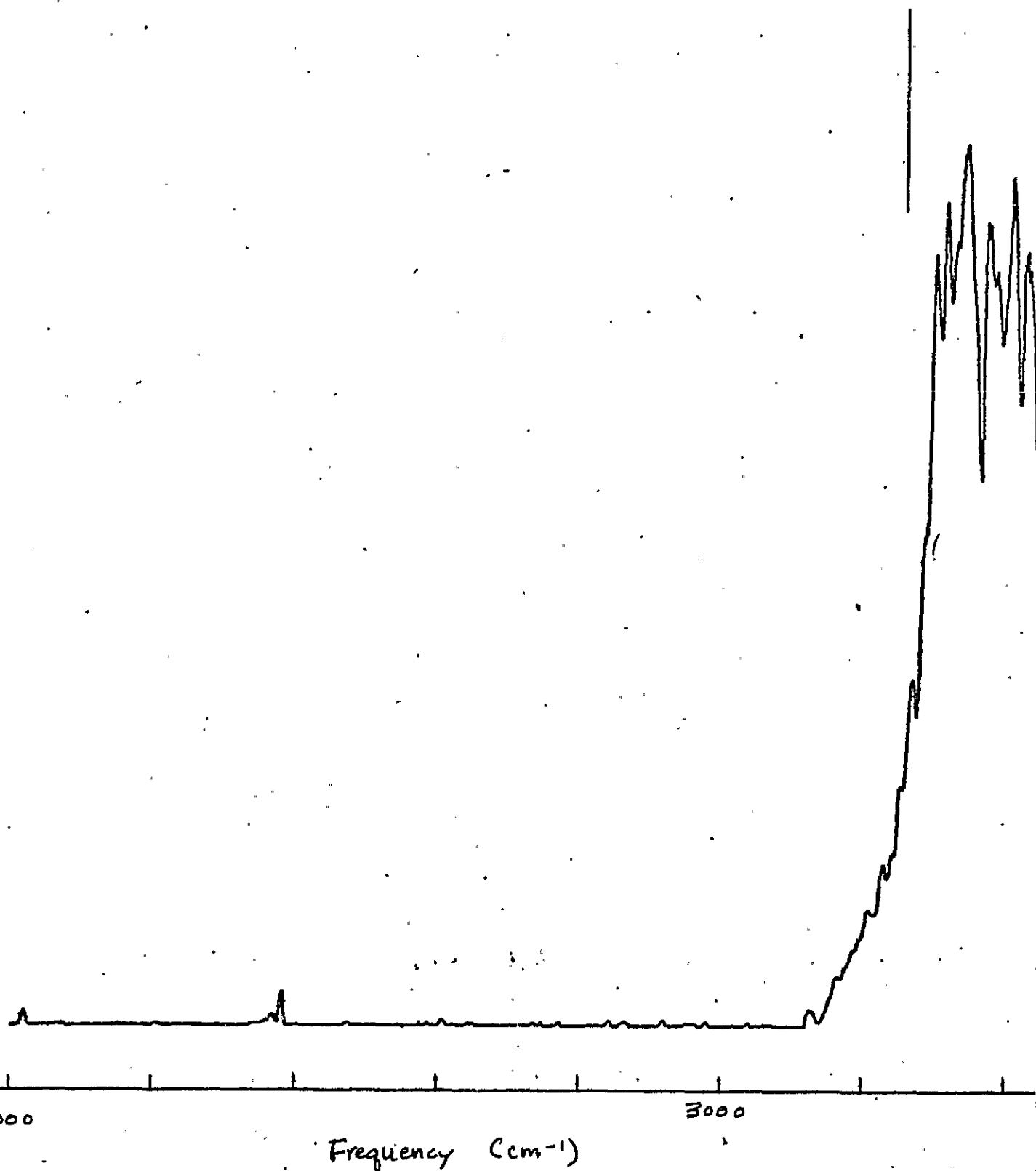




Figure 1 cont.

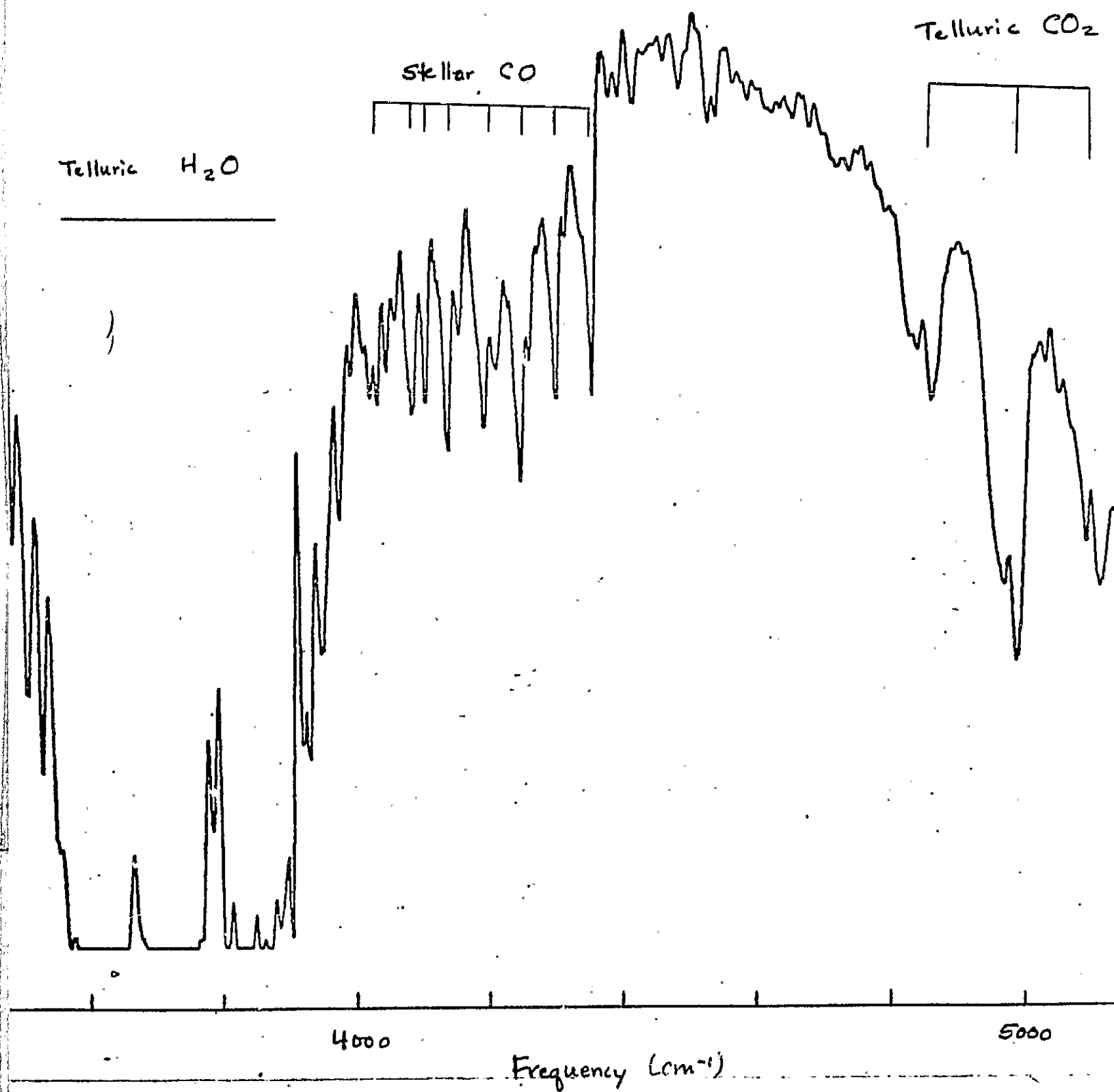


Figure 1 cont.

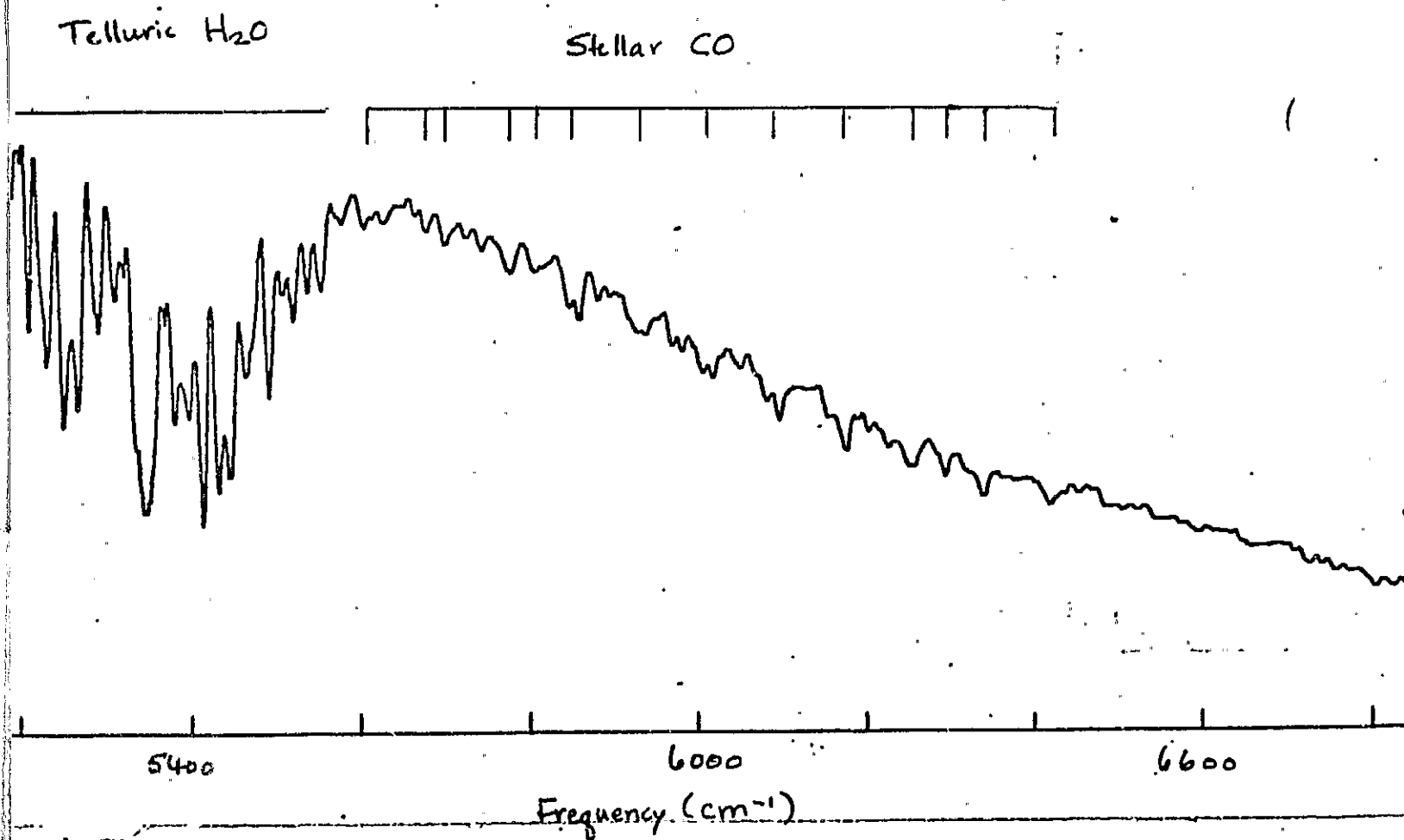


Figure 1 cont.



7000

8000

Frequency (cm<sup>-1</sup>)

Figure 2.

Moon, resolution  $8 \text{ cm}^{-1}$ .

Above: interferogram

Below: spectrum

Detector cutoff

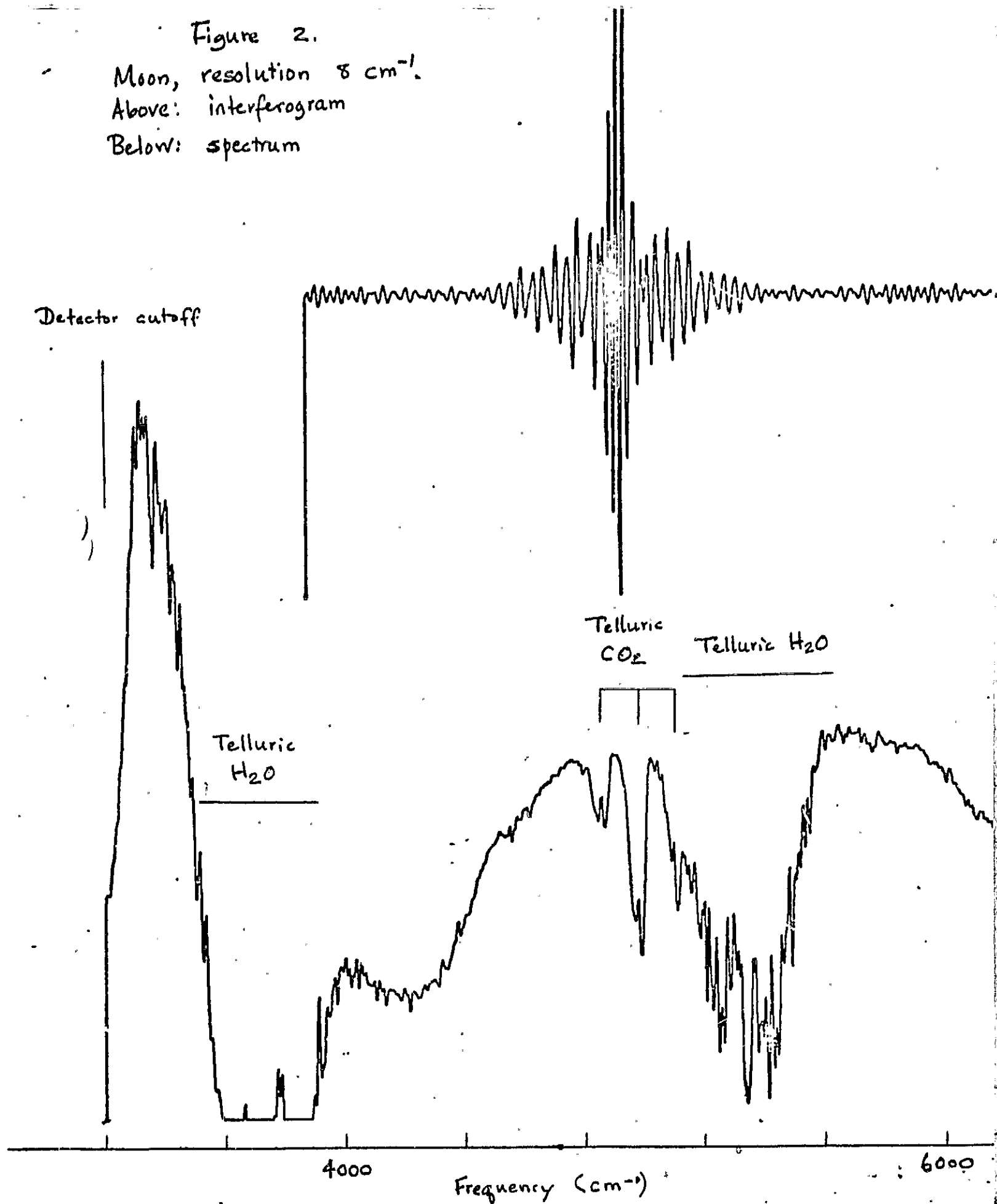
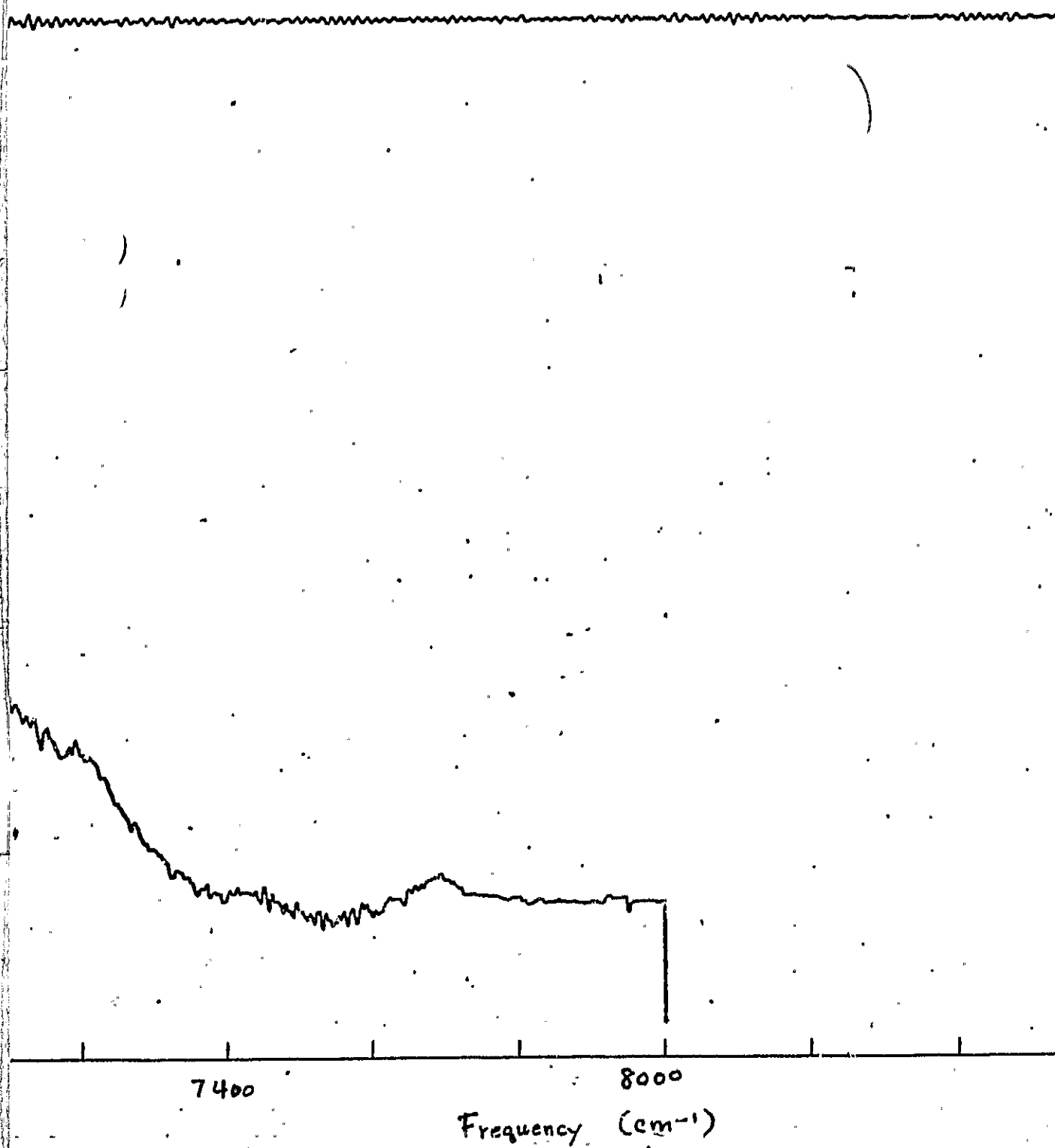


Figure 2 cont.



The detectors supplied with the FTS system are InAs with a solar-blind coated Si lens intended for the spectral interval 1.2-3.3  $\mu\text{m}$  and an InSb detector also with a solar blind Si lens for the region 3.3-5.5  $\mu\text{m}$ . Both are mounted in  $\text{LN}_2$ -cooled dewars. The beamsplitter used for the range 1.2-55  $\mu\text{m}$  is  $\text{CaF}_2$  with a coating of  $\text{Fe}_2\text{O}_3$ . We have also purchased other beamsplitters to extend the spectral range to 0.8  $\mu\text{m}$  on the short end and to 25  $\mu\text{m}$  on the long wavelength end. The appropriate detectors for these regions will be acquired at another time.

The sky compensation system, built by Block, is designed on the double-beam principle though only one detector is used. An imperfection in the  $\text{CaF}_2$  beamsplitter has kept the sky compensation system from working properly, but it is expected that Block will replace the beamsplitter so that the unit can be made to function correctly. Meanwhile, we have undertaken to obtain spectra without the correction for sky emission, though such correction will ultimately be needed for effective work at wavelengths longer than about 3  $\mu\text{m}$ .

#### Initial Results

The instrument has been used in Honolulu for a laboratory program of frost and hydrate spectra by D. Cruikshank and N. Morrison (to be published). Most recently, we used the interferometer on the Cassegrain focus of the Mauna Kea 88-inch telescope and obtained preliminary stellar and planetary spectra. A sample spectrum at 8  $\text{cm}^{-1}$  resolution of Alpha Orionis is shown in Figure 1. It was obtained with 64 scans and the total observing time was approximately two minutes. To obtain similar signal-to-noise at 10 times the resolution, approximately four hours observing time will be required unless the effective sensitivity of the system is improved. Certain improvements are needed — we have identified